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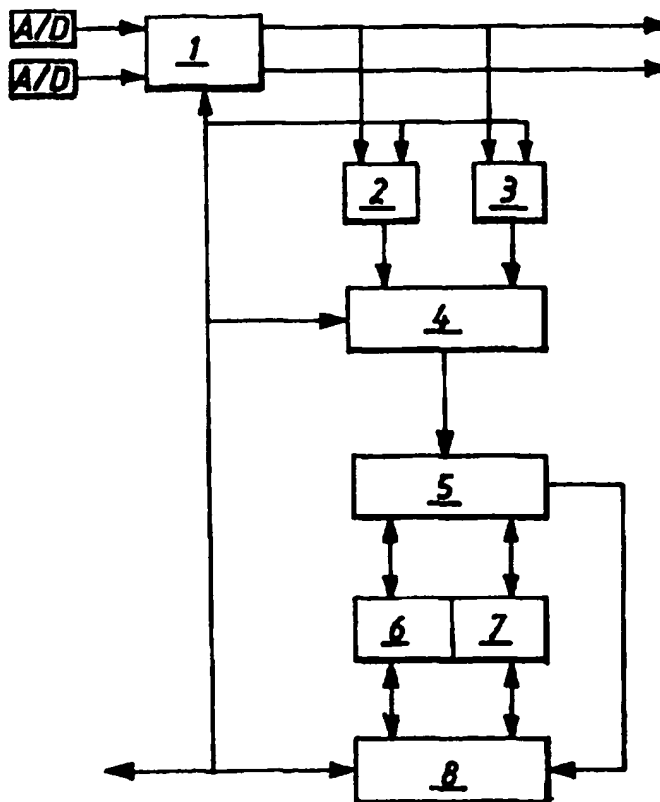
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(57) Abstract

In an OFDM system, pre-FFT synchronisation is performed on the received signal before conversion from the time domain to the frequency domain, i.e. before the signal is subject to FFT processing. Data is transmitted in frames. A plurality of frames may be transmitted as a super-frame. Each super-frame commences with at least one synchronisation frame and is followed by a defined number of information carrying frames. One, or more, synchronisation frames contains a chirp signal. A chirp signal is a sine wave signal having a frequency which changes linearly with time. Two adjacent synchronisation frames may each contain a chirp signal. The chirp signals in adjacent frames have their frequencies changing in opposite senses, i.e. one chirp signal has a frequency which increases with time, the up-chirp, while the other chirp signal has a frequency which decreases with time, the down-chirp. A bit pattern is stored in the receiver which corresponds to the decoded chirp signal, i.e. the chirp signal after it has been digitally processed by the receiver. The received signal is compared, after digital processing, with the stored bit pattern.



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- 1 -

METHOD AND DEVICE FOR SYNCHRONIZATION OF TRANSMITTER
AND RECEIVER IN A DIGITAL SYSTEM.

The present invention relates to a method of, and
apparatus for, synchronising a receiver with a
transmitter in an OFDM (orthogonal frequency division
multiplex) system, more particularly in an OFDM system
in which data is multiplexed into a plurality of frames
which are in turn multiplexed into a super-frame.

In an OFDM system, of the type to which the present
invention relates, one or more frames at the beginning
of each super-frame is/are synchronisation frames. Such
systems may be used for the transmission of radio, or
television, programmes by means of digital radio
transmission. An example of such systems are those to
which the DAB (digital audio broadcasting) standards
relate.

In an OFDM system data is modulated onto a
broadband signal comprising a large number of individual
frequency carriers which form a frequency division
multiplex. The bandwidths of the individual frequency
channels, are small and arranged so that the maximum of
the $\text{sinc}(x)$, ($\text{sinc}(x) = \sin(x)/x$), power spectrum, of
one channel, corresponds with the first minimum in the
 $\text{sinc}(x)$ power spectrum of the adjacent channels. In
other words, the channel separation equals $1/(\text{symbol}$
length), for rectangular symbols. It is for this reason
that adjacent channels are described as "orthogonal".
OFDM systems normally use a FFT (fast fourier transform)
process to demodulate the data signal from the
transmitted signal. Convolution error coding and FFT
may be employed at the modulator (transmitter) stage.
In the receiver, complementary FFT processing is
combined with Viterbi decoding, at the demodulator
stage. This ensures that the overall bit error rate is

- 2 -

very low. This particular variant of OFDM is as known
COFDM (Coded Orthogonal Frequency Division Multiplex).
In recent years COFDM systems have been developed for a
variety of broadcasting applications, e.g. for digital
5 audio broadcasting and high definition TV. For
convenience, in this specification the term OFDM is used
to refer to both OFDM and COFDM.

The known prior art is briefly discussed below:

European patent EP 448,493 discloses a system for
10 transmission of digitally encoded television signals.
The visual information which is transmitted to a mobile
user is split into two parts, one part is used for the
creation of a normal TV picture and the other part is
used, together with the first mentioned part, to create
15 a larger picture.

European patent EP 441,732 discloses a receiver for
digital radio signals. The receiver uses a window
method to minimise inter-symbol interference which
occurs in multipath propagation. In order to minimise
20 the affects of loss of carrier orthogonality at
reception, the receiver is equipped with a time window
module which is used to extract useful samples from the
received signal.

US patent US 5,228,025 discloses a method for the
25 digital transmission of data by radio, preferably to
mobile receivers. The method includes transmission of
synchronisation sequences in the form of at least one
frequency which varies in a known manner at the
receiver. At the receiver, the synchronisation sequence
30 is used for tuning the local oscillator. The
synchronisation sequences consist of at least three
reference sequences and the frequency difference between
two of the sequences is constant.

- 3 -

In an article "OFDM/FM Frame Synchronisation for Mobile Data Communication", William D Warner et al., IEEE 42 (302) August 1993, there is described an OFDM system in which a three stage synchronisation process is used.

5 The three stages are: power detection, coarse synchronisation and fine synchronisation. The synchronisation uses correlation between a transmitted synchronisation sequence and a sequence stored in the receiver.

10 US patent 5,148,451 discloses a synchronisation technique using correlation between a transmitted synchronisation sequence and a synchronisation sequence stored in a receiver. Its application to OFDM is not brought out in the disclosure.

15 PCT patent application W092/16063 discloses a synchronisation technique for use with OFDM systems which employs coarse and fine synchronisation. The system described employs DQPSK (differential quadrature phase shift keying) and is a multi-frame system in which
20 two frames in a super-frame are used for synchronisation. The disclosure refers to a frequency raster, this is a reference to the multiple carrier structure of the OFDM broadband signal and not to a "frequency chirp".

25 Synchronisation techniques applicable to OFDM systems are also described in European patent applications EP 84,787 A1 and EP 529,421 A2.

30 In the first prototype for transmission and reception of DAB (Digital Audio Broadcasting) two synchronisation frames were used. The first frame, called the zero frame, is empty. This frame is used, by the receiver, partly for synchronisation and partly for estimating interference in the channel. The second

- 4 -

frame contains a chirp signal, i.e. a sine wave signal with a swept frequency, that is to say, a sine wave signal in which the frequency varies in a linear manner with time and which sweeps over the entire channel width. This signal is used, by the receiver, partly for timing, i.e. dividing the incoming signal into FFT frames, and partly for estimating the transmission function of the channel. The manner in which the sample clock and carrier frequency are adjusted is not specified in the DAB standards. In the final DAB specification the chirp frame is replaced by a so called TFPC signal (Time Frequency Phase Control) which is used by the receiver both for timing, frequency adjustment and for estimation of the transmission function.

Where OFDM, (or COFDM) is used for the transmission of digital program information, i.e. radio, or TV, a receiver must be synchronised with the transmitter. It should be noted that the transmission of program information, especially video program information requires that very large volumes of data be transferred from transmitter to receiver. Where a chirp signal is used for the synchronisation of a receiver with a transmitter, correlators are used in the receiver for achieving synchronisation. If a full correlation is to be performed on a recieved signal, in real time, the processing requirements in terms of multiplications and additions to be performed per second is enormous. The present invention seeks to alleviate this problem.

The present invention relates to a method of, and apparatus for, pre-FFT synchronisation of a receiver with a transmitter in a digital OFDM, or COFDM, transmission system. Pre-FFT synchronisation is performed on the recieved signal before conversion from the time domain to the frequency domain, i.e. before the signal is subject to FFT processing. Data is

- 5 -

transmitted in frames. Each frame may be intended for reception by the same, or different receivers, or alternatively each frame may be employed in a similar, or different, manner by a receiver. Thus, frames may, but not necessarily, be used to distinguish between data for different receivers, or data to be used for different functions within a receiver. For example, video and audio data may be transmitted in different frames. A plurality of frames may be transmitted as a super-frame. Each super-frame commences with at least one synchronisation frame and is followed by a defined number of information carrying frames. The present invention uses one, or more, synchronisation frames containing a chirp signal. A chirp signal is a sine wave signal having a frequency which changes linearly with time. In a preferred embodiment of the present invention, two adjacent synchronisation frames each contain a chirp signal. The chirp signals in adjacent frames have their frequencies changing in opposite senses, i.e. one chirp signal has a frequency which increases with time, the up-chirp, while the other chirp signal has a frequency which decreases with time, the down-chirp. A bit pattern is stored in the receiver which corresponds to the decoded chirp signal, i.e. the chirp signal after it has been digitally processed by the receiver. The received signal is compared, after digital processing, with the stored bit pattern. The number of identical bits are counted. A chirp signal will have been detected when the number of identical bits is either close to 0, or close to N, where N is the number of binary words into which a frame is divided by sampling. The number of identical bits can be compared with an upper value $A > N/2$, and a lower value $B < N/2$, in order to determine whether, or not, chirp detection has been achieved. It should be noted that correlating two randomly generated signals would, on average, produce $N/2$ identical bits.

- 6 -

The first stage of the synchronisation process is detection of the chirp signal. This is achieved when the number of identical bits in the received signal and the stored bit pattern is greater than "A"; or less than "B". Appropriate values of "A" and "B" can be determined by experiment, or simulation, for $N = 200$, "A" might be selected as 150 and "B" as 50. The correlator generates an output signal which includes a pulse indicating a coarse time setting. This can be used to achieve coarse synchronisation, which is stage two of the synchronisation process.

To reduce the amount of calculation required by the synchronisation processing, use is made of the most significant bit only in the binary words representing the samples of the recieved chirp pulse, i.e. the sign bit.

In an OFDM system, the receiver splits the received signal into two components, I and Q, which are phase displaced by 90° in relation to each other. The two signals can be described as a real signal and an imaginary signal, in accordance with the usual convention of denoting signals with a phase difference of 90° as real and imaginary. The I and Q signals are converted by A to D (analogue to digital) convertors into a sequence of digital words corresponding to each frame. By adding some of these words together to create new words, a reduction in the overall word rate is achieved which reduces the digital processing required. It is the signals which are reduced, or decimated, in this way that are used in the correlation comparison. When coarse synchronisation has been achieved, by detection of the chirp signal, the correlation signal is delayed by one frame and added to itself. The resultant signal is compared with a threshold value, to determine a frequency correction used to achieve fine

- 7 -

synchronisation. After this the detected signal can be divided into frames and the synchronisation signal used to control the FFT process.

5 The present invention relates to a method and apparatus suitable for pre-FFT synchronisation in OFDM broadcast transmission systems. The technique, by using only sign bits in the correlation process, substantially reduces the processing normally required for synchronisation.

10 According to a first aspect of the present invention, there is provided a method of pre-FFT synchronising an OFDM transmission system in which data is transmitted in a frame structure comprising frames and super-frames, each super-frame comprising a
15 predetermined number of frames, at least one frame in each super-frame carrying a chirp signal for use in synchronising a receiver with a transmitter, said method including the step of sampling and digitising a received signal to form a sequence of binary words representing
20 said received signal, and correlating the digitised and sampled received signal with a stored digital representation of said chirp signal, each binary word representing a sample of said received signal including
25 a sign bit, or most significant bit, characterised in that said correlation step is performed using only the sign bits, or the most significant bits, of said binary words.

30 Preferably a local oscillator frequency is varied until an output from said correlation step either exceeds a first predetermined threshold, or falls below a second predetermined threshold.

Preferably each super frame includes a first frame comprising a chirp signal having a frequency variation

- 8 -

with time in a first sense and a second frame comprising a chirp signal having a frequency variation with time in a second sense, said first and second senses being opposed.

5 Each super frame may include an empty frame.

10 Preferably said sequence of binary words representing said recieved signal is reduced by a decimation process so that said correlation step is performed on a sequence of binary words having a word rate less than a frequency at which the received signal is sampled.

15 Said recieved signal may be split into a real component and an imaginary component, said correlation step being performed separately on both said real component and imaginary component.

20 A local oscillator error signal may be derived by measuring the time between two correlation peaks obtained from said correlation step and corresponding to different super-frames, and comparing said time with a number of clock cycles of a local oscillator, within an integer number of super frames.

25 A first signal, derived from an output from said correlation step, may be delayed by a time corresponding to one frame to form a second signal, said first signal may be added to said second signal to form a third signal and said third signal may be compared with a threshold value to determine frame timing in the received signal.

30 Said received signal may be split into a real component and an imaginary component and said correlation step may be performed separately on both

- 9 -

said real component and imaginary component to produce two of said third signals, and said local oscillator may be latched on to its current frequency when one of said two third signals achieves said threshold value.

5 According to a second aspect of the present invention there is provided a receiver for use in an OFDM transmission system in which data is transmitted in a frame structure comprising frames and super-frames,
10 each super-frame comprising a predetermined number of frames, at least one frame in each super-frame comprising a chirp signal for use in synchronising said receiver with a transmitter, said receiver including an analogue to digital convertor arranged to sample and digitise a received signal to form a sequence of binary
15 words representing said received signal, storage means in which is stored a digital representation of a chirp signal, and correlation means arranged to correlate the digitised and sampled received signal with said digital representation of the chirp signal stored in said
20 storage means, each binary word representing a sample of said received signal including a sign bit, or most significant bit, characterised in that said correlation means is adapted to operate only on the sign bits, or the most significant bits, of said binary words.

25 Preferably an output from said correlation means is connected to a comparator means which is arranged to produce an output signal indicating detection of a chirp signal when an output from said correlation means either exceeds a first predetermined threshold, or falls below
30 a second predetermined threshold.

 Preferably said receiver is adapted to receive a signal in which each super frame includes a first frame comprising a chirp signal having a frequency variation with time in a first sense and a second frame comprising

- 10 -

a chirp signal having a frequency variation with time in a second sense, said first and second senses being opposed.

5 Said receiver may be adapted to receive a signal in which each super frame includes an empty frame.

10 Said receiver may include decimation means having an input for receiving an output derived from said analogue to digital convertor and an output connected to an input of said correlation means and arranged to reduce said sequence of binary words representing said received signal so that said correlation means operates on a sequence of binary words having a word rate less than a frequency at which said received signal is sampled.

15 Said received signal may be split into a real component and an imaginary component and a first and second correlation means may be included in said receiver, said first correlation means operating on said real component and said second correlation means operating on said imaginary component.

20 Said receiver may include a frequency error generator for generating a local oscillator error signal derived by measuring the time between two correlation peaks generated by said correlation means corresponding to different super-frames and comparing said time with the number of clock cycles of the local oscillator within an integer number of super frames.

25 Said two correlation peaks may correspond to adjacent super-frames and said integer number of super-frames may be a single super-frame.

30 A first signal, derived from said correlator means,

- 11 -

may be passed to a delay means, arranged to delay said first signal by a time corresponding to one frame, to form a second signal, and said receiver may include adding for adding said first signal to said second signal to form a third signal, and a second comparator for comparing said third signal with a threshold value to determine frame timing in the received signal.

Said receiver may include a numerically controlled local oscillator and a process control means, said process control means being arranged to adjust the frequency of said numerically controlled local oscillator until said third signal achieves said threshold value.

Said received signal may be split into a real component and an imaginary component, and said correlation means may include first and second correlators, said first correlator operating on said real component and said second correlator operating on said imaginary component, each correlator producing an output signal, and said process control means arranged to cause said frequency of said numerically controlled local oscillator to be latched to its current frequency when an output signal from either said first, or second correlator achieves said threshold value.

According to a third aspect of the present invention there is provided a transmitter for use in an OFDM transmission system in which data is transmitted by said transmitter in a frame structure comprising frames and super-frames, each super-frame comprising a predetermined number of frames, at least one frame in each super-frame comprising a chirp signal for use in synchronising a receiver with said transmitter, characterised in that said transmitter is adapted to transmit, in each super-frame, a first frame comprising

- 12 -

a chirp signal having a frequency variation with time in a first sense and a second frame comprising a chirp signal having a frequency variation with time in a second sense, said first and second senses being opposed.

According to a fourth aspect of the present invention there is provided a radio transmission system for transmitting data using OFDM comprising at least one transmitter adapted to transmit data in a frame structure comprising frames and super-frames, each super-frame comprising a predetermined number of frames, at least one frame in each super-frame comprising a chirp signal for use in synchronising a receiver with said transmitter, and at least one receiver characterised in that said at least one receiver is a receiver as specified above.

Preferably said transmitter is a transmitter as specified above.

Said radio system may include a plurality of radio receivers.

Said radio system may include a plurality of transmitters.

According to a fifth aspect of the present invention there is provided a radio transmission system for transmitting data using OFDM comprising at least one transmitter adapted to transmit data in a frame structure comprising frames and super-frames, each super-frame comprising a predetermined number of frames, at least one frame in each super-frame comprising a chirp signal for use in synchronising a receiver with said transmitter, and at least one receiver characterised in that said receiver is synchronised with

- 13 -

said transmitter by means of a method as specified above.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings in which:

5 Figure 1 illustrates, in schematic form, the overall structure of the synchronisation process in an OFDM, or COFDM receiver, according to the present invention.

10 Figure 2 shows a simplified block diagram of the synchronisation elements of a receiver according to the present invention.

15 Figure 3 shows a block diagram of the synchronisation elements of a receiver, according to the present invention, in which reduction, or decimation, of samples is employed.

Figure 4 illustrates the process of reduction, or decimation.

Figure 5 illustrates the super-frame structure used in the present invention.

20 In the embodiment of the present invention described in this specification, data is transmitted in a frame structure made up of frames and super-frames, as illustrated in Figure 5. A super frame comprises an integer number of frames, each of which may contain
25 modulated data. Each super-frame commences with an empty, or zero, frame, followed by two frames containing chirp signals. As previously explained, a chirp signal is a sine wave signal whose frequency varies monotonically with time. In the case of the present
30 embodiment, the frequency of the chirp signal varies

- 14 -

linearly with time. The second frame in the super-frame contains a chirp signal whose frequency increases with time, the up-chirp, and the third frame contains a chirp signal whose frequency decreases with time, the down-chirp. Thus, the sense of frequency variation in the two chirp signals is opposite. It should be noted that, in alternative embodiments, one of the frames containing chirp signals may be omitted.

A frame is a block of data corresponding to the input, or output, of the FFT processor employed in a transmitter, or receiver, of an OFDM system. It exists both in the frequency and time domain. In the time domain it can mean a vector with, or without, a guard interval. In the frequency domain it can mean a full FFT vector, or a vector just containing active carriers. A frame contains an integer number of carriers and an integer number of information bytes. The maximum number of carriers must be less than 0.8 times the FFT size.

A super-frame is used to designate the data from the start of one preamble to the start of the next preamble, and contains an integer number of frames.

The present embodiment of the invention relates to pre-FFT synchronisation of a receiver with a transmitter in an OFDM system. The general construction and operation of OFDM systems is well known in the telecommunications art. For this reason the description of the invention, set out below, is confined to those aspects of an OFDM receiver involved in the synchronisation technique of the present invention. So far as the present invention is concerned, the novel feature of the transmitter is limited to transmission of the frame structure described above.

The present invention employs a three stage

- 15 -

synchronisation process which includes the following stages:

- detection of the OFDM signal, and the synchronisation frames containing the chirp signals;
- coarse synchronisation; and
- fine synchronisation.

For successful FFT processing of a received OFDM signal, the FFT frames in the received signal must be aligned with the receivers FFT frame to within 0.2 ppm. Coarse synchronisation results in a frame alignment to within 1ppm, fine synchronisation results in an alignment to within 0.2 ppm, or better.

Details of the synchronisation control steps are described later in this specification.

Turning now to Figures 1 to 3, a recieved OFDM signal is split into two components, the I and Q components, with a 90° phase separation, which are sampled and digitised by A/D (analogue to digital) convertors. These signals are passed to a frequency adjusting unit 1, containing a numerically controlled oscillator, and operating in a manner well known to those skilled in the art. The frequency adjusting unit operates to bring the frame timing of the received signal into alignment with the FFT frame timing. The numerically controlled oscillator also controls the sampling frequency of the A/D convertors. The output from the frequency adjusting unit 1 is passed to a FFT processor, not shown. Before the FFT processor can demultiplex the received signal, the frequency adjusting unit must be controlled so that it brings the received

- 16 -

frame structure into synchronisation with the FFT frame structure - so called pre-FFT synchronisation. The I and Q components of the signal are passed, together with a stored digital reference signal, representing a chirp signal, to binary correlators, 2 and 3, which include XNOR gates. The output from the binary correlators, 2 and 3, are then passed to a comparator, or threshold detector, 4. The threshold value, for use in comparator 4, is set by the signal processor unit. The output from comparator 4, is a signal indicating that a chirp frame has been detected. This signal is passed to a process control unit, or state machine, 5, which controls the synchronisation process. A frame counter 7, and a sample counter 6, are controlled by, and can be incremented by, the process controller 5. A latch circuit 8, is controlled by process controller 5, and operates to cause the frequency adjusting unit 1, to lock onto synchronisation, when it has been achieved.

Referring now to Figure 3, the frequency adjusting unit "NCO" contains a numerically controlled oscillator and functions as described above. Before the sampled and digitised I and Q components of the received signal are passed to the two correlators, they are subjected to a decimation process, illustrated in Figure 4. The decimation process results in the elimination of a proportion of the samples of the received signal components and hence a reduction in the sample frequency fed to the correlators by e.g. a factor of 4. It should be clearly noted that the use of the term "decimation" does not indicate that 1 in 10 samples are eliminated. This process and the reason for using it are discussed later in this specification. After correlation, the output of the correlators are split, one portion of the split signal is delayed by one frame and the other portion is not delayed. The delayed and undelayed signals are then added. This generates a correlation

- 17 -

pulse which corresponds in time to that between the second and third frames of a super-frame, i.e. to the up-chirp signal and the down-chirp signal. This signal precisely locates the frame structure in the received signal and permits precise synchronisation between the frame structure in the received signal and the FFT processor frame structure, in respect both of frequency and phase. The correlation pulse is detected by a threshold detector, the threshold value of which is set by the signal processor. The outputs from the two threshold detectors, shown in Figure 3, are then fed to a selector, which has an OR function and produces an output, which can be used by the frame sequencer to initialise the FFT frame, from whichever of the two threshold detectors is triggered first.

Returning now to the signal detection and coarse synchronisation stages of the synchronisation process, the output from the A/D convertors shown in Figures 1 to 3 comprise a sequence of binary words each of which represents the magnitude of a sample of the received signal. Only the sign bit, or most significant bit of these words is passed to the binary correlators 2 and 3. The binary correlators compare the received signal with a reference signal representing a chirp signal using a series of XNOR gates. The number of identical bits, i.e. the Hamming weight, of the received signal and the stored representation of the chirp signal is obtained. It should be noted that the input sequence, and stored sequence, of bits can be regarded as a vector and will sometimes be referred to as such in this specification. The output from the correlators 2 and 3 can be regarded as a vector representing the Hamming weight of a comparison between the input signal and stored reference signal representing a chirp signal.

If two randomised independent vectors of length N

- 18 -

are correlated, the output will have, on average, a Hamming weight of $N/2$. If the correlation coefficient between the vectors is 1, the Hamming weight becomes N . If the correlation coefficient between the vectors is (-1), the Hamming weight becomes 0. The output signals from the correlators 2 and 3 must therefore be compared with two limit values, one of which, "A", is greater than $N/2$, and the other of which "B", is less than $N/2$. For $N = 200$, "A" might be 150 and "B" might be 50. If the output signal representing the Hamming weight of the correlation between the recieved signal and reference signal stored in the receiver is greater than "A", or less than "B", a chirp signal has been detected.

Two correlators are used so that both the phase and frequency of the chirp signal can be determined.

The recieved signal is continuously correlated with a stored reference signal representing a chirp signal. The same reference signal is used both for up-chirps and down-chirps. When the received signal is correctly adjusted the output signal from one of the correlators is either close to zero or close to N , the number of samples in the correlation reference signal. The output signal is compared with two threshold signals and, if an output outside these references is detected, an output is generated indicating detection of a chirp signal. If no output is obtained from the correlator, the threshold values are adjusted until detection occurs. The process steps for acquisition of coarse synchronisation, is indicated below. The process steps are controlled by process controller 5, which forms part of a signal processor unit.

Process Steps for clock frequency estimation (acquisition of coarse synchronisation):

- 19 -

1. Set, or change, threshold values for the Hamming weight of the correlation output vector.
2. Initialise the sample/frame counter.
3. Start correlation.
- 5 4. If the chirp signal is detected, go to step 6, else go to step 5.
5. If the time is shorter than a preset time-out, go to step 4, else adjust the threshold values and go to step 1.
- 10 6. Increment the sample/frame counter by 1.
7. If the chirp signal is detected, go to step 10, else go to step 8.
8. If the time is shorter than the pre-set time-out, go to step 9, else adjust the threshold values and go to step 2.
- 15 9. Increment the sample/frame counter by 1, go to step 7.
10. Read the contents in the sample/frame counter.
- 20 11. Estimate the sample clock frequency error and adjust the clock's numerically controlled oscillator.
12. If the calculated clock frequency error is greater than a pre-set value E, go to step 2.
- 25 Coarse adjustment of the receiver's FFT-window (frame timing):

- 20 -

1. Pre-set the sample/frame counter.
2. When a chirp is detected go to step 3.
3. Enable the sample/frame counter and enable data flow to the FFT processor.
- 5 4. When a chirp is detected go to step 5.
5. Transfer contents of sample/frame counter into latch (8, of Figure 2) and transfer to signal processor, start timing sync-check in the signal processor, go to step 4.
- 10 If the content of the sample counter is close to the expected value and the frame counter is equal to 1, the timing system is in sync. If the sample/frame counters have values outside the expected range it means that the timing synchronisation is lost and a resync of
- 15 the system is necessary.

Timing sync-check in the signal processor:

1. If the content of the sample counter is not correct, go to step 2.
- 20 2. Increment out of sync counter in the signal processor.
3. If out-of-sync counter \leq out-of-sync limit, go to step 1 else go to step 4.
4. Receiver out-of-sync., perform resynchronisation.

25 The DC-offset for the received signal is estimated using data from the zero frame. The zero frame complex data is stored in a FIFO which can be read by the signal

- 21 -

processor. DC off-sets for the real and imaginary components of the signal are estimated separately.

$$DC_{\Re} = \sum_{\text{zeroframe}} (\text{received signal})_{\Re}$$

$$DC_{\Im} = \sum_{\text{zeroframe}} (\text{received signal})_{\Im}$$

Where \Re denotes the real part of a complex parameter, and \Im denotes the imaginary part of a complex parameter.

5 Since the DC-offset errors are assumed to change very slowly, it is important not to introduce extra noise by updating the DC off-set value too often, or too abruptly. The estimates from each frame are therefore averaged over a large number of frames before they are
10 applied to the hardware.

 The FFT window in the receiver must be aligned with the FFT window in the transmitter, as already explained. This is achieved by means of a correlation process carried out between the received signal and a locally
15 stored chirp signal. The result of this correlation is a very sharp pulse signal that can be used for estimating and correcting local clock errors, and adjusting the timing of the received signal and the sampling thereof. However, correlation calculations can
20 impose a heavy overhead on digital processing capacity in the receiver. It has been found that two strategies can be used to reduce the processing overhead imposed by correlation, without adversely affecting the precision of the synchronisation process. First, the correlation
25 process can be performed using only the sign bit, or most significant bit of each binary word representing a

- 22. -

digitised sample of the received signal, and secondly the number of samples on which correlation is performed can be reduced, either by an averaging process, or an elimination process, so that the number of samples used in the correlation per frame is reduced from, say, 512, to 128, say, i.e. by a factor of 4. Other reduction factors can be used in this decimation process.

The correlation process can be represented by the following equations:

$$C_c(n)_R = \sum_{k=0}^{K-1} \text{sign}[C_t(k)]_R * \text{sign}[C_r(k+n)]_R$$

and

$$C_c(n)_S = \sum_{k=0}^{K-1} \text{sign}[C_t(k)]_S * \text{sign}[C_r(k+n)]_S$$

where:

C_t = the locally stored chirp signal

C_r = the received chirp signal

C_c = the output signal from the correlator

The sequences C_t and C_r can be decimated, or reduced, as described above. It is not possible for the correlator to handle the full 16K samples per second produced by the A/D convertors. The output signal from the correlator is, therefore, the Hamming weight for the stored and received chirp signal; as represented by the sign bits of the sample binary words. Where the input samples are reduced by a factor of 2, or 4, only the central part of the chirp signal is used. The correlation peak is very narrow and the signal energy in

- 23 -

the correlator is concentrated within this pulse. There is, therefore, good immunity to interference. However, the synchronisation process breaks down when the interference is so strong that it affects the most significant bit in the binary words representing the received sample, i.e. when the interference signal is of comparable strength to the data carrying signal.

The sample clock frequency can be estimated by observing the time between correlation peaks over a number of cycles of the sampling clock. The signal is observed after carrier compensation. The number of clock cycles that should occur in a super-frame is known. When two, or more, correlation peaks have been received and detected, the sampling clock frequency that should be used can be estimated.

If n_r clock cycles are observed between correlation peaks; and

n_0 clock cycles should occur between correlation peaks when synchronisation has been fully acquired; and

f_0 is the frequency of the receivers numerically controlled oscillator, from which the sampling rate is derived, (known to about ± 1 ppm); and

Δf_{clk} is the clock error frequency;

then Δf_{clk} can be calculated using the equation below:

$$\Delta f_{clk} = f_0 \left(1 - \frac{n_r}{n_0}\right)$$

The observation interval, for which n_r and n_0 are determined may extend over more than one super-frame.

- 24 -

As previously mentioned, in connection with Figure 3, the output signal from the correlator is delayed by one frame and added to the undelayed output from the correlator. The resultant signal is then compared with a threshold value. As already explained the I and Q components of the received signal are processed separately through separate correlators, in parallel with each other. There are thus two correlator outputs which are compared with threshold values, and which ever signal achieves the threshold value first is used in the synchronisation process.

After pre-FFT synchronisation is fully acquired, the received signal is divided into frames for FFT processing.

It should be noted that the description set out above, has been confined to those elements of an OFDM receiver, system and method of synchronisation that are believed to be novel. Details of the full design of an OFDM receiver are available in the prior art and those skilled in the art will be familiar with such designs.

The embodiments of the invention described above are examples of the way in which the present invention may be implemented. Variations and modifications of the invention will be readily apparent to those skilled in the art. The scope of the present invention should therefore be judged from the following claims.

- 25 -

CLAIMS

1. A method of pre-FFT synchronising an OFDM transmission system in which data is transmitted in a frame structure comprising frames and super-frames, each super-frame comprising a predetermined number of frames, at least one frame in each super-frame carrying a chirp signal for use in synchronising a receiver with a transmitter, said method including the step of sampling and digitising a received signal to form a sequence of binary words representing said received signal, and correlating the digitised and sampled received signal with a stored digital representation of said chirp signal, each binary word representing a sample of said received signal including a sign bit, or most significant bit, characterised in that said correlation step is performed using only the sign bits, or the most significant bits, of said binary words.

2. A method as claimed in claim 1, characterised by varying a local oscillator frequency until an output from said correlation step either exceeds a first predetermined threshold, or falls below a second predetermined threshold.

3. A method as claimed in either claims 1, or 2, characterised in that each super frame includes a first frame comprising a chirp signal having a frequency variation with time in a first sense and a second frame comprising a chirp signal having a frequency variation with time in a second sense, said first and second senses being opposed.

4. A method as claimed in any previous claim, characterised in that each super frame includes an empty frame.

- 26 -

5. A method as claimed in any previous claim, characterised by reducing said sequence of binary words representing said recieved signal by a decimation process so that said correlation step is performed on a sequence of binary words having a word rate less than a frequency at which the received signal is sampled.

6. A method as claimed in any previous claim, characterised by splitting said recieved signal into a real component and an imaginary component, said correlation step being performed separately on both said real component and imaginary component.

7. A method as claimed in any previous claim, characterised by deriving a local oscillator error signal by measuring the time between two correlation peaks obtained from said correlation step and corresponding to different super-frames, and comparing said time with a number of clock cycles of a local oscillator, within an integer number of super frames.

8. A method as claimed in claim 7, characterised in that said two correlation peaks correspond to adjacent super-frames and said integer number of super-frames is a single super-frame.

9. A method as claimed in any previous claim, characterised in that a first signal, derived from an output from said correlation step, is delayed by a time corresponding to one frame to form a second signal, in that said first signal is added to said second signal to form a third signal and in that said third signal is compared with a threshold value to determine frame timing in the received signal.

10. A method as claimed in claim 9, characterised by adjusting a local oscillator frequency until said third

- 27 -

signal achieves said threshold value.

5 11. A method as claimed in claim 10, characterised in that said recieved signal is split into a real component and an imaginary component and in that said correlation step is performed separately on both said real component and imaginary component to produce two of said third signals, said local oscillator being latched on to its current frequency when one of said two third signals achieves said threshold value.

10 12. A receiver for use in an OFDM transmission system in which data is transmitted in a frame structure comprising frames and super-frames, each super-frame comprising a predetermined number of frames, at least one frame in each super-frame comprising a chirp signal
15 for use in synchronising said receiver with a transmitter, said receiver including an analogue to digital convertor arranged to sample and digitise a recieved signal to form a sequence of binary words representing said received signal, storage means in
20 which is stored a digital representation of a chirp signal, and correlation means arranged to correlate the digitised and sampled received signal with said digital representation of the chirp signal stored in said storage means, each binary word representing a sample of
25 said received signal including a sign bit, or most significant bit, characterised in that said correlation means is adapted to operate only on the sign bits, or the most significant bits, of said binary words.

30 13. A receiver as claimed in claim 12, characterised in that an output from said correlation means is connected to a comparator means which is arranged to produce an output signal indicating detection of a chirp signal when an output from said correlation means either exceeds a first predetermined threshold, or falls below

- 28 -

a second predetermined threshold.

14. A receiver as claimed in either claims 12, or 13, characterised in that said receiver is adapted to receive a signal in which each super frame includes a first frame comprising a chirp signal having a frequency variation with time in a first sense and a second frame comprising a chirp signal having a frequency variation with time in a second sense, said first and second senses being opposed.

15. A receiver as claimed in any of claims 12 to 14, characterised in that said receiver is adapted to receive a signal in which each super frame includes an empty frame.

16. A receiver as claimed in any of claims 12 to 15, characterised in that said receiver includes decimation means having an input for receiving an output derived from said analogue to digital convertor and an output connected to an input of said correlation means and arranged to reduce said sequence of binary words representing said received signal so that said correlation means operates on a sequence of binary words having a word rate less than a frequency at which the received signal is sampled.

17. A receiver as claimed in any of claims 12 to 16, characterised in that said received signal is split into a real component and an imaginary component and in that a first and second correlation means are included in said receiver, said first correlation means operating on said real component and said second correlation means operating on said imaginary component.

18. A receiver as claimed in any of claims 12 to 17, characterised in that said receiver includes a frequency

- 29 -

error generator for generating a local oscillator error signal derived by measuring the time between two correlation peaks generated by said correlation means and corresponding to different super-frames and in that said time is compared with the number of clock cycles of a local oscillator, within an integer number of super frames.

19 A receiver as claimed in claim 18, characterised in that said two correlation peaks correspond to adjacent super-frames and said integer number of super-frames is a single super-frame.

20. A receiver as claimed in any of claims 12 to 19, characterised in that a first signal, derived from said correlator means, is passed to a delay means arranged to delay said first signal by a time corresponding to one frame to form a second signal, and in that the receiver further includes adding means for adding said first signal to said second signal, to form a third signal and a second comparator for comparing said third signal with a threshold value to determine frame timing in the received signal.

21. A receiver as claimed in claim 20, characterised in that said receiver includes a numerically controlled local oscillator and a process control means, said process control means being arranged to adjust the frequency of said numerically controlled local oscillator until said third signal achieves said threshold value.

22. A receiver as claimed in claim 21, characterised in that said recieved signal is split into a real component and an imaginary component, in that said correlation means includes first and second correlators, said first correlator operating on said real component and said

- 30 -

second correlator operating on said imaginary component, each correlator producing an output signal, and in that said process control means is arranged to cause said frequency of said numerically controlled local oscillator to be latched to its current frequency when an output signal from either said first, or second, correlator achieves said threshold value.

23. A transmitter for use in an OFDM transmission system in which data is transmitted by said transmitter in a frame structure comprising frames and super-frames, each super-frame comprising a predetermined number of frames, at least one frame in each super-frame comprising a chirp signal for use in synchronising a receiver with said transmitter, characterised in that said transmitter is adapted to transmit, in each super-frame, a first frame comprising a chirp signal having a frequency variation with time in a first sense and a second frame comprising a chirp signal having a frequency variation with time in a second sense, said first and second senses being opposed.

24. A radio transmission system for transmitting data using OFDM comprising at least one transmitter adapted to transmit data in a frame structure comprising frames and super-frames, each super-frame comprising a predetermined number of frames, at least one frame in each super-frame comprising a chirp signal for use in synchronising a receiver with said transmitter, and at least one receiver characterised in that said at least one receiver is a receiver as claimed in any of claims 12 to 22.

25. A radio transmission system as claimed in claim 24 characterised in that said transmitter is a transmitter as claimed in claim 23.

- 31 -

26 A radio system as claimed in either of claims 24, or 25, characterised in that said radio system includes a plurality of radio receivers as claimed in any of claims 12 to 22.

5 27. A radio system as claimed in any of claims 24 to 26, characterised in that said radio system includes a plurality of transmitters as claimed in claim 23.

10 28. A radio transmission system for transmitting data using OFDM comprising at least one transmitter adapted to transmit data in a frame structure comprising frames and super-frames, each super-frame comprising a predetermined number of frames, at least one frame in each super-frame comprising a chirp signal for use in synchronising a receiver with said transmitter, and at
15 least one receiver characterised in that said receiver is synchronised with said transmitter by means of the method claimed in any of claims 1 to 11.

1 / 2

Fig. 1

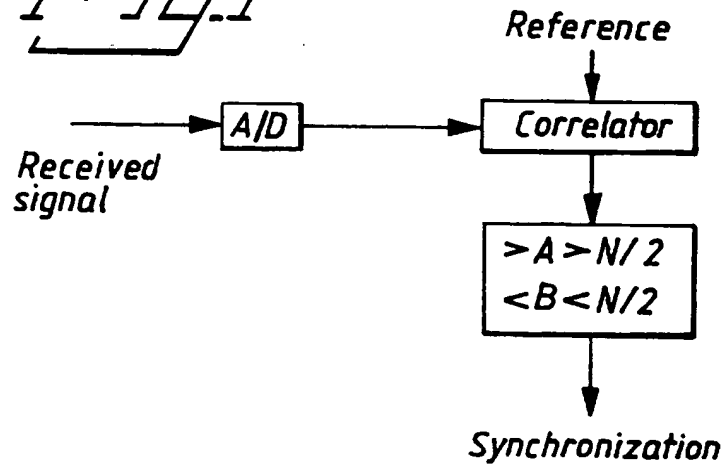
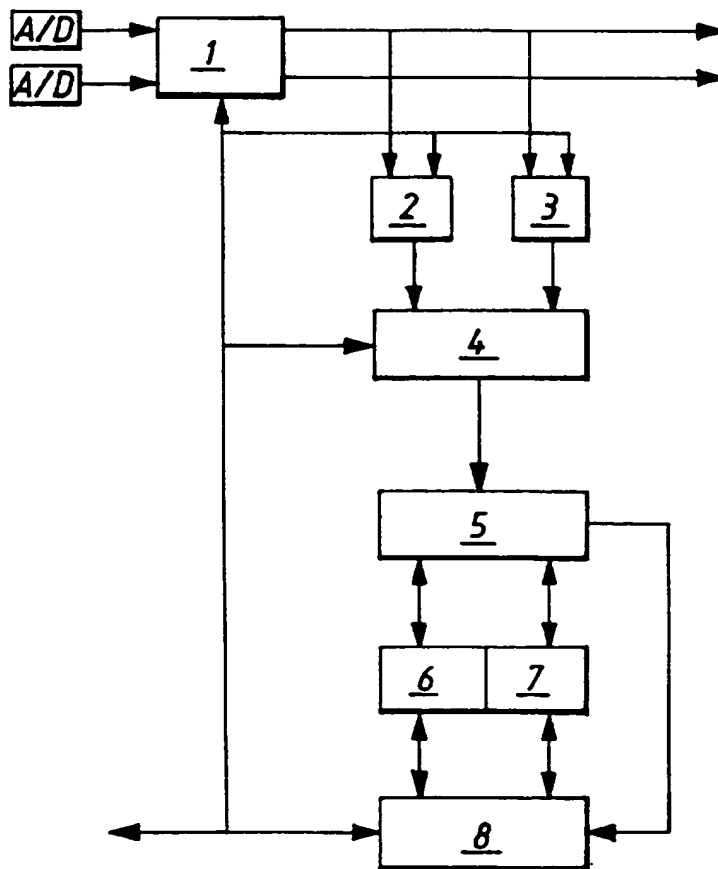
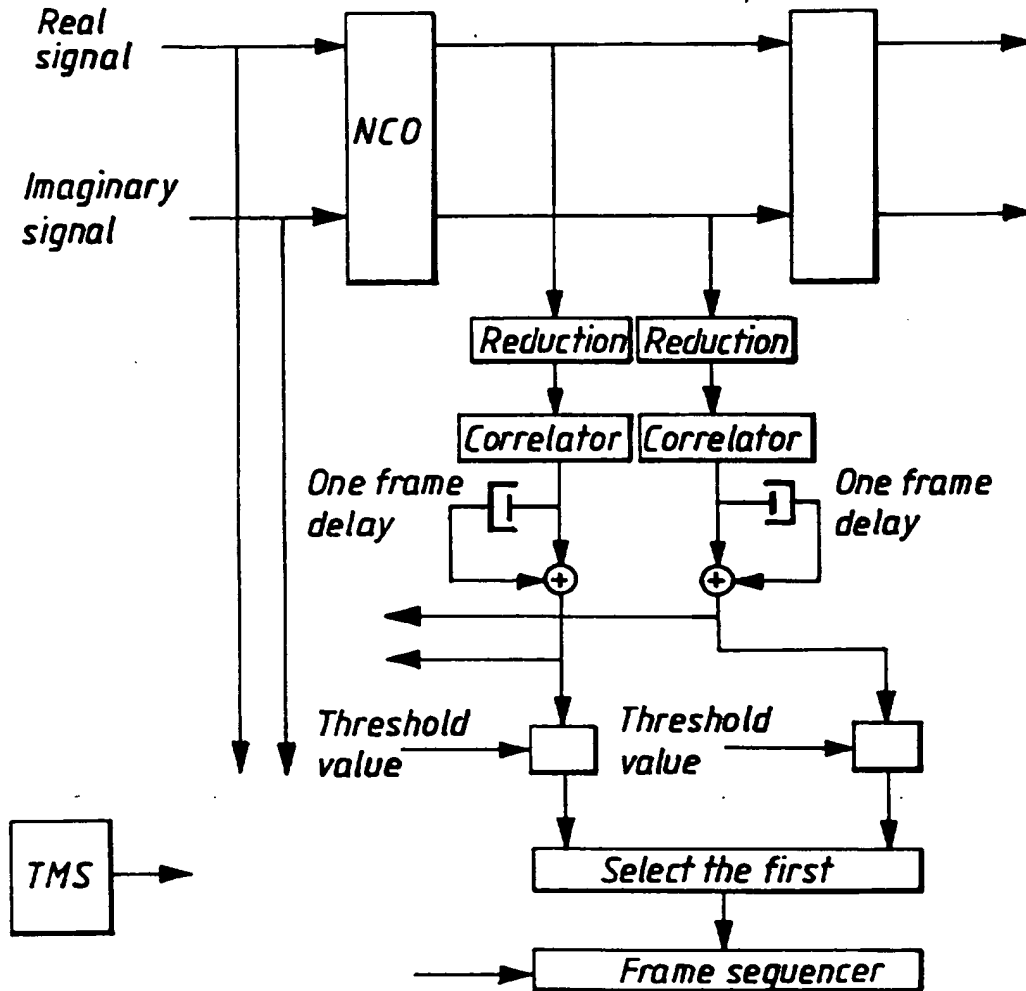


Fig. 2



2 / 2

Fig. 3



Original sequence

Fig. 4

Reduced sequence

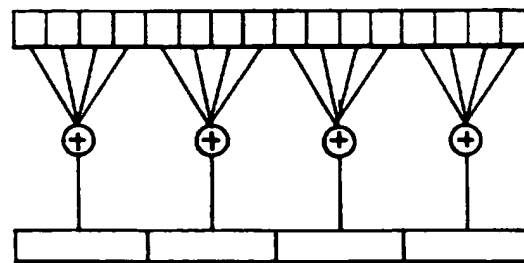


Fig. 5

